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Impact of fatty infiltration of the rotator cuff on reverse total shoulder arthroplasty outcomes: a systematic review

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Background and hypothesis: The impact of preoperative fatty infiltration of specific rotator cuff muscles on the outcomes of reverse total shoulder arthroplasty (rTSA) has not been well defined. Preoperative fatty infiltration of the shoulder musculature will negatively affect rTSA outcomes.
Methods: A comprehensive literature review was conducted as per the Preferred Reporting Items for Systematic Reviews and Meta-analyses using PubMed, Embase, OVID Medline, Scopus, Cinahl, Web of Science, and Cochrane databases for original, English-language studies evaluating effect of fatty infiltration of shoulder musculature on rTSA outcomes published from January 1, 2000 to present. Blinded reviewers conducted multiple screens. All included studies were graded based on the level of evidence, and data concerning patient demographics and postoperative outcomes were extracted.
Results: A total of 11 articles were included, including one level I article, three level III articles, and seven level IV articles. The review consisted of 720 patients and 731 shoulders (320 women and 157 men), with a mean age of 72.4 years. A single deltopectoral approach was performed for a majority of studies (627/731 shoulders), followed by a superolateral approach (70/731 shoulders) and a single transdeltoid approach (4/731 patients). Eleven studies reported data specifically about preoperative fatty infiltration of the rotator cuff musculature; the teres minor was studied most widely (298/731 shoulders), followed by the subscapularis (256/731 shoulders) and infraspinatus (232/731 shoulders). The Constant score (562/731 shoulders) and American Shoulder and Elbow Surgeons score (284/731 shoulders) were the most common recorded outcome scores. Fatty infiltration of the teres minor, supraspinatus, and infraspinatus was associated with worse range of motion after rTSA.
Conclusion: Preoperative fatty infiltration of the rotator cuff, particularly of the teres minor and infraspinatus, has a negative impact on subjective patient outcomes and restoration of range of motion, especially external rotation, after rTSA. The impact of fatty infiltration of the other rotator cuff muscles remains unclear, which may be due to intersurgeon differences in the handling of the remaining rotator cuff muscles or differences in implant design. The evaluated literature provides information on which patients can be educated about probable outcomes and restoration of function after rTSA.

Traditionally, massive or irreparable rotator cuff tears have been treated surgically by total shoulder arthroplasty (TSA), in which the humeral head and glenoid cavity are replaced with prostheses to reduce pain and increase active range of motion (ROM).[2] Reverse TSA (rTSA) has grown in popularity in recent years, with its

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alternative design relying on re-engineering shoulder dynamics—augmenting the moment arm of the deltoid to better enable forward elevation and abduction—to create an effective joint in the absence of a sufficient rotator cuff.[3-5,7,9,10,19,27] In cases with major or complete rotator cuff tears, rTSA can help to restore external rotation and forward elevation.[3-5,7,9]

The increasing usage of rTSA has come with some limitations in its effects. rTSA has been shown to have significantly high rates of complications due to a variety of factors—acromial fractures, scapular notching, infection, hematoma, baseplate failure, and instability—with complication rates ranging from 16% to 68%.[4,5,7,9,25,26,29] Studies have delved into determining preoperative factors that may have clinically significant effects on the outcomes in rTSA.[8] One such factor is fatty infiltration (FI) or degeneration of the rotator cuff.[20] With the altered design of rTSA relying less on the rotator cuff, the impacts of FI of the rotator cuff musculature on outcomes of rTSA are less well understood, particularly the impact that FI of specific rotator cuff muscle has on outcomes. In addition, many patients who undergo rTSA have varying degrees of rotator cuff pathology.[21] The purpose of this review was to systematically evaluate the literature to determine the impacts of FI of the rotator cuff on the outcomes of rTSA. We predict that outcomes of rTSA will be significantly, negatively impacted by increasing amounts of rotator cuff FI.

Materials and methods

Information sources

A comprehensive literature review was conducted as per the Preferred Reporting Items for Systematic Reviews and Meta-analyses using OVID Medline, Embase, PubMed Medline, Cochrane Database of Systematic Reviews (via OVID), Cochrane Central Register of Controlled Trials (via OVID), Scopus, Cinahl, and Web of Science from inception up to April 15, 2021.

Search

A search strategy was created using a combination of keywords and database-specific headings related to each concept including rTSA and FI of the shoulder musculature. Please refer to the supplementary data for complete and reproducible search strategies. Non-English and nonhuman studies were excluded from the search. Duplicates were removed using ProQuest RefWorks (Ex Libris, Jerusalem, Israel).

Eligibility criteria

For studies to be considered for inclusion, they had to discuss patients undergoing a primary rTSA with data on FI gathered before operation and with follow-up data detailing the status of the shoulder after operation. Postoperative follow-up was not limited to a minimum timeline during the initial search to prevent limiting the potential available literature.

Publication year limit was set within each database search from January 2000 to April 2021. Studies were only included if published in the English language. Studies that focused on bilateral rTSA, revision rTSA, shoulder resurfacing, shoulder hemiarthroplasty, rTSA due to trauma, or TSA were not included in the review. If there was no discussion of preoperative FI or postoperative follow-up, studies were excluded. Studies that focused purely on FI of the deltoid and no rotator cuff muscles were excluded. Studies which included concomitant procedures (eg, fracture fixation, cadaver studies, preprints) were not included. Types of publications excluded from this review included addresses, comments, editorials, case reports, and narrative review (ie, level V evidence).

Data collection process

The data collection process consisted of multiple, tiered reviews. All reviews were conducted using Rayyan QCRI (Doha, Qatar). For the first review, reviews were performed by two authors in an independent, blinded fashion based on the title and abstract. Studies were included if the title or abstract indicated data collection of preoperative FI of the shoulder, procedure of an rTSA, and follow-up and analysis of rTSA results after operation. Articles marked for inclusion were then subjected to a full-text screening, again by two blinded, independent reviewers to ensure each study met the inclusion criteria listed above (SP and BL).

Once each article had been screened by two reviewers, a third, independent reviewer resolved any conflicts that were present (AP). Once the full-text screening was complete, the final article bank was collated in Rayyan, including the full-text PDFs of each study. Relevant data from each study were then extracted and recorded by one of three team members in a shared Excel document on a private Google Drive.

Summary of measures and results

For each included study, the level of evidence was determined by two independent reviewers (SP and BL) and settled by a third in case of conflict (AP). Assignment of levels was given in a systematic approach. Level I was assigned to all randomized controlled trials and systematic reviews. Prospective cohort studies were considered level II. All retrospective case-control studies were considered level III. Level IV studies were those of case series.

Each article was assigned to one of three reviewers (SP, BL, or AP) for data extraction. To preclude bias in data extraction, the variables and data that were extracted were decided on before the extraction process beginning. For each study analyzed, the following data were extracted: number of patients, number of shoulders, sex of patients, mean age, study design, inclusion criteria, exclusion criteria, mean follow-up time, surgical technique, preoperative FI of shoulder musculature by individual muscle when specified, preoperative and postoperative functional scales, preoperative and postoperative ROM measurements, patient satisfaction, complications, revisions, radiographic findings, and conclusions (Tables I and II, Supplementary Tables S1 and S2).

Risk of bias

The search procedure was standardized at each level and within each database to ensure minimal bias. Screening at each level and for each study was performed by two reviewers in a blinded fashion to eliminate interobserver bias. A third reviewer was used in a necessarily unblinded fashion to settle any conflicts, posing the possibility of slight interobserver bias in those scenarios. Levels I through IV were only included in the review, minimizing any bias from studies of lesser quality. The greatest risk of bias comes from the limited number of studies on the subject of FI and rTSA. Within this limited pool of current literature, only a smaller percentage had the main objective focused on FI's effect on the outcomes in rTSA, creating risk of bias toward limited results. In addition, a formal assessment for bias in the form of the methodological index for nonrandomized studies was performed by two independent reviewers (SP and BL) with conflicts resolved by an independent third reviewer (AP).[23] An overall ideal score for a noncomparative study is 16, and an ideal overall score for a comparative study is 24.

Table I
An overview of demographics and focus of the studies included in the systematic review.

	Patients	Shoulders	Mean age (yrs)	Single deltopectoral approach (studies)
# included	720	731	72.4	9

Table II
A breakdown by rotator cuff muscle of the severity of fatty infiltration encountered across each study as well as the consensus from the included studies about the impact of fatty infiltration of that specific rotator cuff muscle on outcomes of rTSA.

Grade*	Teres minor	Subscapularis	Infraspinatus	Supraspinatus
0	54	26	7	6
1	113	82	44	39
2	37	65	100	65
3	15	10	25	40
4	10	4	11	37
Category				
Moderate (grade 0-2)	53	37	8	0
Severe (grade 3-4)	16	32	37	0
Total shoulders evaluated	298	256	232	187
Impact of fatty infiltration	Consistently associated with poorer external rotation after rTSA and worse clinical outcomes (Greiner et al 2015, Simovitch et al 2007, Boileau et al 2006, Hung et al 2021)	Not consistently correlated with worse outcomes (Greiner et al 2009, Puzzitiello et al 2021)	One study found negative impacts on postoperative external rotation and lateral elevation (Wiater et al). One study found it had no impact on external rotation (Boileau et al 2006). One study found an association with scapular notching (Levigne et al 2008)	No correlation with ROM or patient-recorded outcomes (Puzzitello, Wiater)

rTSA, reverse total shoulder arthroplasty; *ROM*, range of motion.
*For studies that reported fatty infiltration only as an average, these numbers were excluded from the abovementioned table; hence, the number of shoulders graded in these tables differs from the total number of shoulders included in overall analysis (Greiner 2010, Yoon, Wiater). One study (Merolla) did not give discrete numbers for patients who underwent rTSA and their respective musculature status, so they were also not included in the abovementioned table.

A score less than 14 or less than 22 for a noncomparative study or a comparative study, respectively, was considered a "B" grade. Of the included articles, 2 were grade A,[18,24] with the remainder being grade B.

Results

Study selection

From the initial searches of all databases, 542 articles were identified (Fig. 1). After screening as detailed in the Methods section, a total of 11 articles were included in the qualitative analysis, including one level I article, three level III articles, and seven level IV articles.

Synthesis of results

Overall, the review included 720 patients and 731 shoulders. However, the study by Merolla et al discussed both rTSA and TSA but did not give a discrete number of rTSAs studied; therefore, this number is not included in the total number of patients or shoulders reported previously and in Table I, but this study was included in the review and discussion of results as their results were broken down by arthroplasty type.[24] The population included in the studies was predominantly female, with 320 female patients compared with 157 male patients. One study did not give a sex breakdown of their patients, and therefore, these patients are not included in the reported male female numbers.[22] The average age of the patients in the studies was 72.4 years old (Table I).

Surgical techniques were largely uniform across all 11 studies—all but two studies used a deltopectoral approach to the joint for all operations.[3,5,13,14,16-18,21,24,28,31] Other approaches that were used include a single transdeltoid approach[5] or a superolateral approach.[17] Boileau et al transitioned from a single transdeltoid approach to a deltopectoral approach after four cases because of concerns about damage to the deltoid and the need for access to the humeral diaphysis in some cases.[5] Glenoid bone grafting was used in two studies.[14,18] Greiner et al were specifically comparing the standard technique with a lateralized technique, and glenoid bone grafting was implemented in 34 of 34 shoulders to achieve lateralization of the center of rotation.[14] Merolla et al used glenoid bone grafting in nine of 83 shoulders to achieve adequate lateralization.[18] One study described using a combined transfer of the latissimus dorsi and teres major tendons in addition to standard rTSA with an anatomic target of the posterolateral humerus for the tendon reattachment.[3] With regard to the handling of the remaining rotator cuff, 6 studies specifically mentioned repairing the subscapularis or what remained of the muscle belly.[3,5,13,14,18,21]

Eleven studies reported data specifically about FI of the rotator cuff musculature (Table II, Supplementary Table S1). All studies used the grading criteria as put forth by Goutallier and Fuchs.[11,12] However, studies differed with how they grouped various grades of FI and what specific muscles were investigated. The teres minor was looked at most often, with 10 studies describing the FI of this muscle specifically.[3,5,13,14,16,18,24,28,31] A variety of clinical and functional scores and scales were used to measure postoperative improvement after rTSA, with the Constant score being used most often (n = 9), followed by the American Shoulder and Elbow Surgeons (ASES) score (n = 5). Multiple studies demonstrated a significant improvement in clinical outcomes postoperatively.[3,5,13,14,18]

With regard to FI of the rotator cuff and its impacts on outcomes, Simovitch et al found that the patients with less FI of the teres

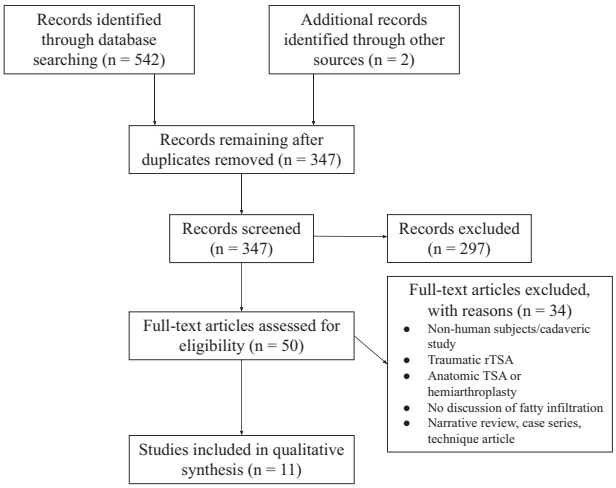

Figure 1 Flow chart of the systematic review screening process. *rTSA*, reverse total shoulder arthroplasty.

minor (stage 0-2) had a significantly better Constant score postoperatively (83 ± 15.5%) than those shoulders with higher grade FI (61 ± 12.6%, $P < .01$).[24] Similarly, Hung et al found that the ASES score postoperatively was significantly lower in those with teres minor hypertrophy (77.3 ± 22.8 vs. 84.2 ± 16.9, hypertrophy vs. normal muscle volume, $P = .0.2$).[17] However, two studies found that there were no significant differences between patients with minimal FI and those with moderate or severe FI when comparing clinical outcomes.[13,21]

With regard to postoperative ROM, multiple studies found that FI of the rotator cuff was associated with worse ROM after rTSA. They found that FI of the teres minor is associated with decreased external rotation postoperatively.[5,14,24] There were also studies that found preoperatively FI of the infraspinatus negatively impacted postoperative active anterior elevation and external rotation.[18,28] However, Boileau et al found that FI of the infraspinatus did not have a significant impact on postoperative external rotation.[5] One study found that there were no significant impacts on ROM due to FI of the supraspinatus.[28] Wiater et al also found that there were no significant impacts on postoperative ROM secondary to FI of the subscapularis or teres minor.[3] Furthermore, one study that looked at rTSA in patients with an intact rotator cuff found that there was no impact of FI on postoperative ROM.[21]

Only one included study was a level I randomized control trial that examined the impacts of lateralization of the glenosphere on outcomes of rTSA.[14] Although they did find that patients had better outcomes after a lateralized rTSA with bone grafting, they did not examine rotator cuff FI in detail. However, they did find that patients without major degeneration of the teres minor that had a lateralized implant had significantly improved external rotation (Δ42 ± 28 vs. Δ16 ± 26, $P = .39$) compared with patients with a standard implant.[14]

One study specifically examined preoperatively factors that influenced scapular notching, a common complication of rTSA, and found that high-grade FI of the infraspinatus was associated with higher rates of scapular notching.[17] Other commonly reported complications included acromial stress fractures,[13,14,31] nerve palsies which were largely transient,[3,5,21] and deep infection[9] among other less common complications. Some studies discussed the need for revision, which was largely due to recurrent instability or postoperative fractures,[3,13] although there were also studies that reported no need for revision at the completion of follow-up.[5,21]

Discussion

Summary of evidence

The impact of FI of the rotator cuff on the outcomes of rTSA is a complex topic, partially due to rTSA being a relatively new procedure and partially due to the variety of surgical techniques that are used to restore as much functionality as possible. In addition, there is a lack of well-powered, prospective cohort studies that evaluate this particular preoperative factor. Despite this relative paucity of cohort and randomized control trials, the available literature does provide some insight into the effects of FI of the cuff on clinical and functional outcomes after rTSA.

In general, studies found that preoperative FI of the rotator cuff negatively impacted both postoperative functional outcomes and clinical scores.[5,14,16,18,24,28] Although Puzzittiello et al did not find any significant differences in clinical scores or ROM between patients with minimal and those with moderate or severe FI of the rotator cuff, the study population only included patients with an intact rotator cuff.[21] Although there are a wide range of indications for rTSA, it is relatively uncommon for this procedure to be performed in patients with an intact rotator cuff. Among the studies included in this review, 8 specifically mention cuff tear arthropathy or a massive, irreparable rotator cuff tear as inclusion criteria,[3,5,13,14,24,28,31] whereas only two studies operated on patients with intact rotator cuffs.[18,21] Another study found no significant correlation of FI with postoperative clinical scores and no significant difference in Constant scores in a subgroup analysis comparing low- (Goutallier 0-2) and high-grade (Goutallier 3-4) FI of each rotator cuff muscle.[13] However, only 18 patients in this study had magnetic resonance imaging, so it is possible that sample size was a limiting factor in distinguishing between subgroups given that the study also found that overall Constant scores improved postoperatively for all patients.[13]

Although there may not be a clear consensus about impacts of overall rotator cuff FI on rTSA outcomes, the data are clearer with regard to FI of the teres minor. Although the teres minor plays a relatively minor role in stability of the glenohumeral joint and external rotation in patients with an intact rotator cuff, in patients with supraspinatus or infraspinatus tears, the teres minor must counteract the subscapularis to provide joint stability. Furthermore, with loss of the posterior deltoid, the main external rotators of the shoulder become the infraspinatus and teres minor.[1] In addition, the teres minor becomes the main external rotator of the shoulder in the setting of infraspinatus insufficiency; although rTSA can aid in restoring active elevation, the teres minor plays an important role in restoring external rotation after this procedure.[30]

Although there have been previous studies showing the negative impact of teres minor FI, the consensus among the studies included in this review is less clear cut. Four studies in this review that specifically examined FI of the teres minor found that it had negatively impacted both clinical scores and external rotation after rTSA.[5,14,16,24] Two studies found a significant difference in postoperative external rotation between patients with low-grade FI of the teres minor compared with those with high grade, with high-grade FI being associated with ~10-15° less external rotation postoperatively.[13,24] Simovitch et al did find that patients with higher-grade preoperative FI of the teres minor had less active external rotation preoperatively (19 degrees vs. 9 degrees, grade 0-2 vs. grade 3-4, $P < .01$). However, the group with worse preoperative FI also had significantly less increase in postoperative external rotation (Δ9 ± 15.8 vs. Δ-7 ± 17.3, grade 0-2 vs. grade 3-4, $P < .001$).[24] Hung et al also found that severe hypertrophy of the teres minor was associated with worse ASES scores postoperatively (73.3 ± 22.8 vs. 84.2 ± 16.9 [$P = .02$]).[16] They found that, even after

adjusting for confounding variables such as preoperative muscle quality, rotator cuff tendon tear size, and implant positioning, teres minor hypertrophy was the only significant negative predictor of the ASES score after rTSA.[16] However, one of these studies also used a lateralized implant design with bone augmentation of the glenoid and found that patients with a lateralized implant had greater external rotation than those with a standard implant when patients with teres minor hypertrophy were excluded.[6,14,15] Although the overall consensus was that teres minor FI negatively affects rTSA outcomes, Greiner et al did not find any association between teres minor integrity and clinical outcomes or active external rotation.[14] They speculate that this is due to a change in biomechanics and force vectors in rTSA implants, although this conflicts with not only the other studies in this review but also those trials that implement tendon transfers to compensate for FI of the teres minor to aid in restoration of external rotation.[3] In addition, another study found that FI of the teres minor did not correlate with a lack of external rotation; they suspect that this may have been due to a lack of power as relatively few patients ($n = 2$) in their study had high-grade FI of the teres minor.[28] As discussed previously, Puzzitello et al did not find any impact of FI of the teres minor on postoperative outcomes.[21]

One study used an latissimus dorsi transfer in addition to a teres major transfer (latissimus dorsi and teres minor), and they found a significant improvement in external rotation postoperatively.[1] These results show that latissimus dorsi and teres minor transfer in rTSA may be a reliable method for restoring external rotation and should be considered in patients with teres minor deficits or FI for optimal outcomes.

Although the design of rTSA generally dictates the resection of the supraspinatus, most studies did not detail their handling of all rotator cuff muscles, with some not even discussing if they repaired or resected the subscapularis.[17,24,28,31] Although this rotator cuff muscle is often completely torn in patients receiving an rTSA or is resected during the operation, there are studies that still looked at FI, and we therefore felt it was most accurate to include these data (Table II). In particular, one study performed rTSA in patients with intact rotator cuffs, and they found no impact of FI of the supraspinatus on outcomes.[21] Another study did not find any correlation between FI of the supraspinatus on postoperative outcomes.[28] In addition, many studies did not clarify their handling of the remaining rotator cuff, so we are including their results about the supraspinatus to be thorough.

This review is not without limitations, largely due to the quality of evidence in the included studies. Although rTSA is increasing in popularity, there are few cohort or randomized control trials that assess preoperative FI and its impacts on outcomes. Therefore, most of the data on FI of the rotator cuff in rTSA come as adjunct data from many studies, rather than being the main focus. In addition, there were many different types of implant designs used among the included studies (Supplementary Table S1); four studies specifically mention lateralization of the implant, either on the humeral or glenosphere component.[13,18,21,24] Given that this can alter the biomechanics of the implant and the relative impact that each muscle has on ROM and, therefore, patient satisfaction with a procedure and its outcomes, this impacts the strength of conclusions that we can draw from this review.

Conclusion

rTSA is a relatively new operative technique to restore shoulder functionality in older individuals with otherwise irreparable rotator cuff tears or debilitating glenohumeral osteoarthritis. The reviewed literature consistently demonstrated that preoperative FI of the rotator cuff, particularly of the teres minor, has a negative impact on the restoration of ROM, especially external rotation, after rTSA. The impact of FI of the other rotator cuff remains unclear, which may be due to intersurgeon technical differences in the handling of the remaining rotator cuff muscles or differences in prosthetic design. Nevertheless, preoperative FI of the rotator cuff has the potential to degrade outcomes and, therefore, should be evaluated further. The evaluated literature provides a valid data point on which patients can be educated about probable outcomes and restoration of function after rTSA.

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Supplementary Data

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